
Gravitational Lensing of the Most Distant Known Supernova, SN1997ff

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Abstract

We investigate the effect of gravitational lensing on the farthest known supernova, SN1997ff. The SN was found at $z \sim 1.7$ in the Hubble Deep Field North and is most likely of Type Ia. Due to our poor knowledge of the properties of the lensing foreground galaxies, we conclude that large magnification effects are possible for reasonable lens parameter values implying that this single SN does not put any strong constraints on the cosmological parameters, grey dust obscuration or luminosity evolution of SNIa until we can model the lensing with high accuracy.

1. Introduction

A primary goal for cosmology is to determine the total energy density of the Universe, Ω and its constituents. It has been long recognised that this goal is achievable through the study of the redshift-distance relation of Type Ia supernovae (SNe). The relation is sensitive to different values of the cosmological parameters and this difference is more prominent at high redshifts. Therefore, the recently discovered SN at $z \sim 1.7$ [1] might prove to be invaluable in this respect. However, different systematic effects such as obscuration by grey dust, luminosity evolution of Type Ia SNe and gravitational lensing are also possibly more severe at high redshifts. In Ref. [2, 3], the systematic effects of gravitational lensing on a large sample of SNe have been investigated. Here, (with more details in Ref. [4]), we investigate the effects of gravitational lensing due to galaxies lying close to the line-of-sight to SN1997ff, generalising the work in Refs. [5] and [1] by investigating the combined effects from a larger number of galaxies and estimating the masses and velocity dispersions of the lensing galaxies from the measured luminosities. Riess et al. [1] argued that the observed brightness of SN1997ff suggests that there cannot be a sizeable luminosity evolution for Type Ia's nor significant extinction by dust. Our work shows that the possible lensing magnification effects are large enough that the data is also consistent with an intrinsically dimmer supernova,

or with significant dust density along the line-of-sight.

2. Method

From the Hubble Deep Field North (HDF-N; [6]), we obtain the relative positions and redshifts of galaxies lying in the proximity of the line-of-sight to SN1997ff. All (11) galaxies within $0 \leq z \leq 1.7$ and which are lying closer than 10 arc-seconds to the line-of-sight to SN1997ff and its host galaxy have been included in the study. We model the matter distribution of the galaxies as truncated isothermal spheres characterised by their velocity dispersion, v , which can be estimated from the Faber-Jackson relation

$$\frac{v}{v_*} = \left(\frac{L}{L_*} \right)^{0.25} = 10^{0.1(M-M_*)}. \quad (1)$$

Here, M is the absolute magnitude of the galaxy as measured in the b_J magnitude system and L is the luminosity. The star indicates typical galaxy values on v , L and M (and the mass, m , below). We calculate M by performing cross-filter K-corrections (assuming early-type galaxy spectra) on the observed magnitudes in the r and i bands (ST magnitude system) into rest-frame b_J .

To estimate the masses of the lensing galaxies, we combine the observed luminosities with the mass-to-luminosity ratio [7]

$$\frac{m}{m_*} = \left(\frac{L}{L_*} \right)^{1.25} = 10^{0.5(M_*-M)}, \quad (2)$$

valid for early-type galaxies lying in the fundamental plane. From the velocity dispersion and mass of the galaxies, we can compute the truncation radii of the halos. The magnification and deflection of the light from SN1997ff are calculated by using the multiple lens-plane method [8, Ch. 9] where the mass of each of the lensing galaxies is projected onto a plane at the galaxy redshift. Next, the deflection angle and magnification in each plane is computed and by tracing the light-rays backwards from the observer to the source, we can determine the magnification and position of the ray in the source plane. Our calculations have been made using $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$ and the filled beam approximation when calculating cosmological distances. A typical value of $v_* = 238$ km/s was obtained in Ref. [9] for this cosmology.

3. Results and discussion

3.1. Magnification

In Fig. 1., the magnification of SN1997ff is given as a function of the mass normalisation in the left panel and of the velocity dispersion normalisation in the

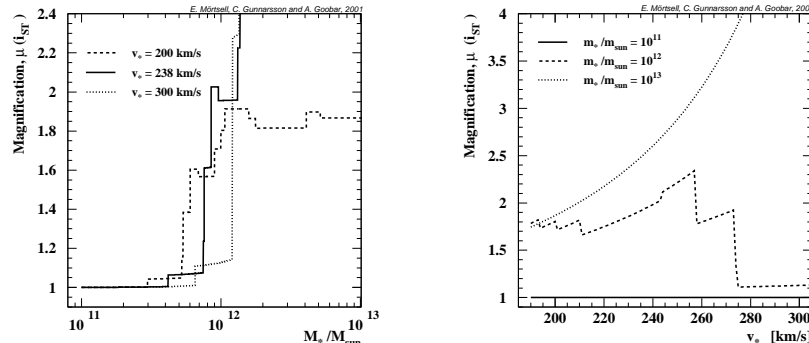


Fig. 1. The magnification, μ , as a function of the typical galaxy mass (left panel) and μ as a function of typical galaxy velocity dispersion (right panel). Both as obtained from the i_{ST} band.

right panel. The masses and velocity dispersions are calculated from the observed luminosities i_{ST} -band but the r_{ST} -band give very similar results. For a circularly symmetric lens, the magnification is determined by the mass within the radius defined by the impact parameter of the light-ray and the surface mass density (or *convergence*) at this radius. The effect of the convergence here is to increase the magnification. Therefore, a light-ray that is passing a plane outside a halo for some specific values of m_* and v_* might pass inside the same halo for some other values, thereby gaining the convergence component of the magnification or vice versa. This is what causes the discontinuities in the magnification in the plots. Of course, these effects are unphysical in the sense that they are very sensitive to the specific modeling of the halos, in this case the steepness of the density profile and the cut-off radii. It is also an indication that lensing effects are very model dependent, and thus very detailed, individual modeling of the lensing galaxies is necessary to make robust predictions of the magnification.

3.2. Clues from host galaxy

The appearance of the host galaxy might offer some clues to the magnitude of the lensing effect. Riess et al. [1] studied the lensing effects of the foreground galaxy closest to the line-of-sight and concluded that the probability of a large magnification is small with such a small ellipticity as is observed (axis ratio ~ 0.85). For a single lens, this is true but when including all foreground galaxies close to the line-of-sight, the situation proves to be much more complicated. The results in Ref. [4] shows that there is no simple relation between magnification

and ellipticity when more than one lens is included in the study.

4. Conclusions

Our lensing analysis show that a large range of magnifications of SN1997ff is possible for reasonable values of the galaxy masses and velocity dispersions. The value of the magnification is very sensitive to details in the modelling of the matter distribution in the lensing galaxies. The apparent (lack of) ellipticity of the host galaxy can be shown not to put any strong constraints on the magnitude of the magnification effect. Thus we conclude, that in order to use the apparent magnitude of a single high redshift SN to infer the values of any cosmological quantities, or even to place meaningful limits on the possible dimming of Type Ia SNe by intergalactic grey dust or luminosity evolution, very careful modelling of the galaxies along the line-of-sight is needed in order to control the systematic effects from lensing.

This work has been carried out together with Edvard Mörtzell and Ariel Goobar. The author would like to thank Lars Bergström, Joakim Edsjö and Peter Nugent for helpful discussions and Tomas Dahlén for providing galaxy spectral templates. I would also like to thank the Swedish Research Council for financial support.

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